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A. Sotiropoulos
J. Ruze

Haystack Calibration Antenna

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123

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LINCOLN LABORATORY

HAYSTACK CALIBRATION ANTENNA

A. SOTIROPOULOS

Group 61

J. RUZE

Division 3

TECHNICAL REPORT 367

15 DECEMBER 1964

LEXINGTON MASSACHUSETTS

ABSTRACT

The gain of a horn-reflector antenna with an aperture of 65.30 square feet has been measured over a frequency range of 2.7 to 16.0 Gcps. This report describes the experimental measurements, the data with best-fit curves, and a linear regression analysis which permits confidence limits to be set on the gain estimate.

Accepted for the Air Force
Stanley J. Wisniewski
Lt Colonel, USAF
Chief, Lincoln Laboratory Office

TABLE OF CONTENTS

HAYSTACK CALIBRATION ANTENNA

I. INTRODUCTION

Evaluation of the 120-foot-diameter Haystack antenna for communications, and radar and radio astronomy applications requires the measurement of gain. Conventional techniques such as direct substitution of a gain standard are impractical because of the large minimum range required for the transmitter-to-antenna distance.

When measuring antenna gain, an acceptable criterion for the minimum separation R between the source antenna and the antenna under test is $R = 2D^2/\lambda$, where λ is the operating wavelength, and D is the antenna aperture diameter. At this distance, the ratio of measured gain to the gain at $R = \infty$ is theoretically 0.987. At $R = D^2/\lambda$, this ratio is 0.95. When the $2D^2/\lambda$ criterion is applied directly to the 120-foot-diameter Haystack antenna, the distance R at 7.75 Gcps is 43 statute miles, and at 16.0 Gcps, R is 90 miles. A reliable test site at these ranges is very nearly impossible; however, a convenient source for use in performing substitution gain measurements is one of the bright radio stars. Since standard gain horns are relatively low-gain devices which range from 18.0 db at S-band to 24.7 db at K_u-band and are incapable of detecting signals from the bright radio sources, they cannot be used directly to determine the gain of the Haystack antenna. A reasonable approach is to calibrate another antenna of sufficient gain to be useful for detecting astronomical signals and yet small enough so that precise gain measurements could be made on an available antenna test range.

For this purpose, a horn-reflector antenna was obtained for use as the gain standard for the Haystack paraboloid. The gain of the horn-reflector antenna was measured in the region from 2.7 to 16.0 Gcps. Descriptions are given of the antenna, the antenna test site, the measurements and their corrections with estimated tolerances, and the evaluation of the data.*

II. HORN-REFLECTOR ANTENNA

A horn-reflector antenna[1,2] approximately 20 feet long was selected. The antenna's relatively simple design, which allows it to be used over a wide band of frequencies, and its unusually low noise temperature were considered advantageous for our purpose. The horn-reflector site is 120 feet east of the Haystack antenna[3] and positioned so that the radio astronomy equipment shelter can be used for either the 120-foot Haystack reflector or the feed of the horn reflector, thereby increasing the flexibility of the system. The mechanical arrangement of the horn is such that the longitudinal axis of the horn is aligned in the east-west direction and rotates about this

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* Arthur Sotiropoulos performed the experimental measurements, obtained the polynomial of best fit, and prepared the corresponding portions of this report. John Ruze is responsible for the Appendix and the linear regression analysis.

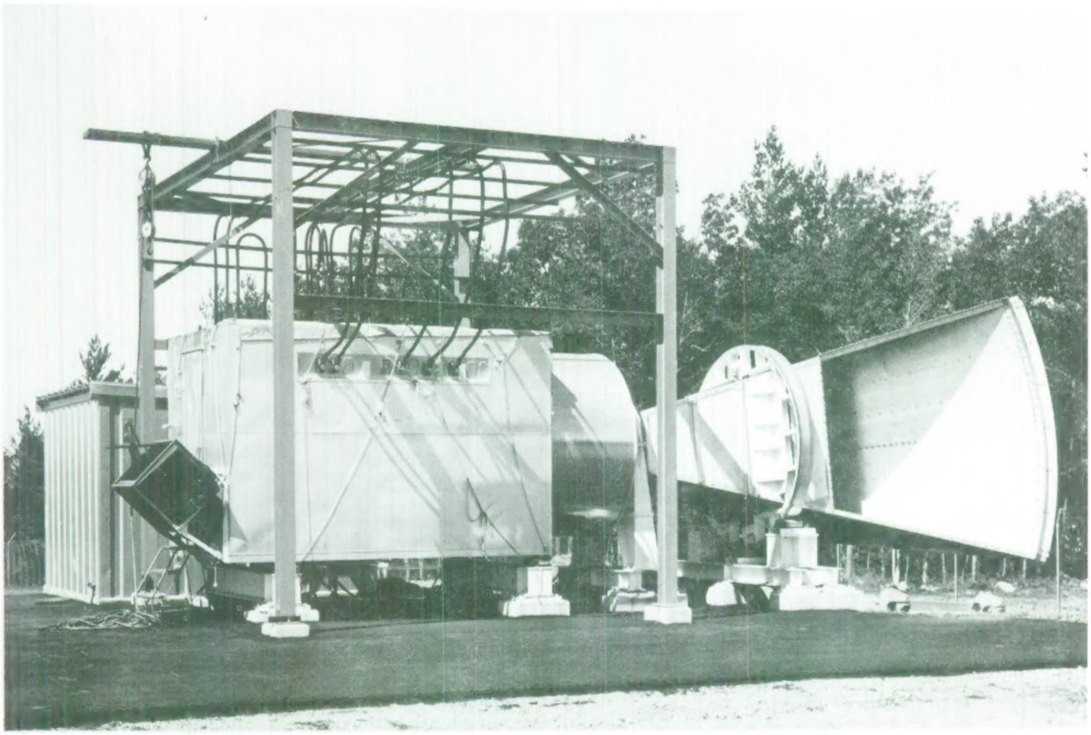

Fig. 1. Horn-reflector antenna in use with radio astronomy equipment room.

axis through a rotary joint at the equipment shelter position. The horn-reflector antenna beam sweeps along the meridian, and the bright radio sources are allowed to drift through the beam. (See Fig. 1.)

The horn-reflector antenna design is based on geometric optics and consists of a square electromagnetic horn utilized as a 90° offset feed for a sector of a paraboloidal reflector. In this manner, the spherical wavefront which illuminates the paraboloid section is converted to a plane wavefront at the trapezoidally shaped aperture. The input to the horn is an $11\frac{1}{2}$-inch square aperture, and a cast aluminum hyperbolic taper reduces the large square opening to a 2.812-inch-inside-diameter circular waveguide.

Five copper electroformed conical-to-rectangular tapers were constructed as transducers between the 2.812-inch circular opening and the different waveguide transmission line sizes in the frequency range 2.7 to 16.0 Gcps. The tapers are rotatable so that either longitudinal or transverse linear polarization is provided. Longitudinal polarization is defined as that direction parallel to the longitudinal axis; transverse polarization is that direction normal to the longitudinal axis in the plane of the projected aperture.

The projected aperture area was calculated to be 65.30 square feet with a half-apex angle of 14°30'30" and a focal length of 93.138". This calculation differs by 0.05 db from the manufacturer's calculation of 64.57 square feet.

III. ANTENNA TEST FACILITY

The Lincoln Laboratory antenna test facility[4] has the capability of satisfying the minimum range requirement for the gain calibration of the horn-reflector antenna. This test site includes

three fully instrumented measuring stations with a transmission distance of 2000 feet. The transmitter and horn-reflector antenna are positioned close to the ground and make use of the controlled combination of direct and ground-reflected rays for producing a well-defined interference pattern at the test-antenna aperture. The amplitude distribution of this interference pattern is dependent upon the wavelength of the transmitted energy, the distance between the antennas, and the heights of both antennas.

The horn-reflector antenna was mounted on a pedestal located on the roof of the antenna range receiver building, and a signal source was positioned in the transmitter building at a distance of 2030 feet. (See Fig. 2.)

Jull's method[5] of calibrating a horn reflector antenna utilized a "mirror" range with measurements performed in the Fresnel zone. However, in our case we operated in the far field and did not require large near-field corrections.

Before making gain measurements, the vertical amplitude distribution of the illuminating field over the aperture of the horn-reflector antenna was measured with a horn mounted on a motor-driven carriage attached to an 18-foot triangular tower. Representative measurements are shown in Fig. 3. The greatest variation in the amplitude taper of the field was 0.62 db which produces a theoretical gain reduction of 0.15 db (see Appendix). The average of the ripples of the illuminating field was obtained by varying the height of the standard gain horn near the center of the horn-reflector aperture.

IV. MEASUREMENTS

The standard gain horn was mounted to the rear of the horn-reflector antenna and at the center of its projected aperture. Each anntenná was alternately placed in the illuminating field, and a variable precision waveguide attenuator was adjusted to equalize the signals observed at a receiver. The difference in power level between the horn-reflector antenna and the standard gain horn was then read directly from this attenuator. With the standard gain horn in a position which corresponds to the average of the maximum and minimum value of the illuminating field, a total of six measurements was obtained for every point plotted in Fig. 4.

The microwave antenna gain standards used for these measurements were fabricated in accordance with the design procedures published by Slayton[6] and based on Schelkunoff's gain equation. Since the gain measurements were taken with five separate tapers, a cross check was made at a common frequency when the equipment change involved a new taper and the use of the adjacent band standard gain horn. At this identical frequency, the two sets of data were noted for deviations. In all four instances, the deviations were within the measurement error tolerance.

Deviations from the mean value at each frequency were determined from the measured data. All the deviations were then used to determine the root-mean-square deviation which was calculated to be 0.15 db. This is a measure of the ability to repeat identical measurements taken under the same conditions. The root-mean-square deviation includes a transmitter drift, receiver drift, meter-reading error, the small probability of a slightly different waveguide connection at each reading, changes in range reflections, and any human or equipment errors introduced each time a change is made.

Preliminary measurements were made on two types of waveguide attenuators: a fixed attenuator permanently attached to the horn-reflector antenna to bring the different power levels closer together; and the precision variable attenuator which was mentioned previously. Both

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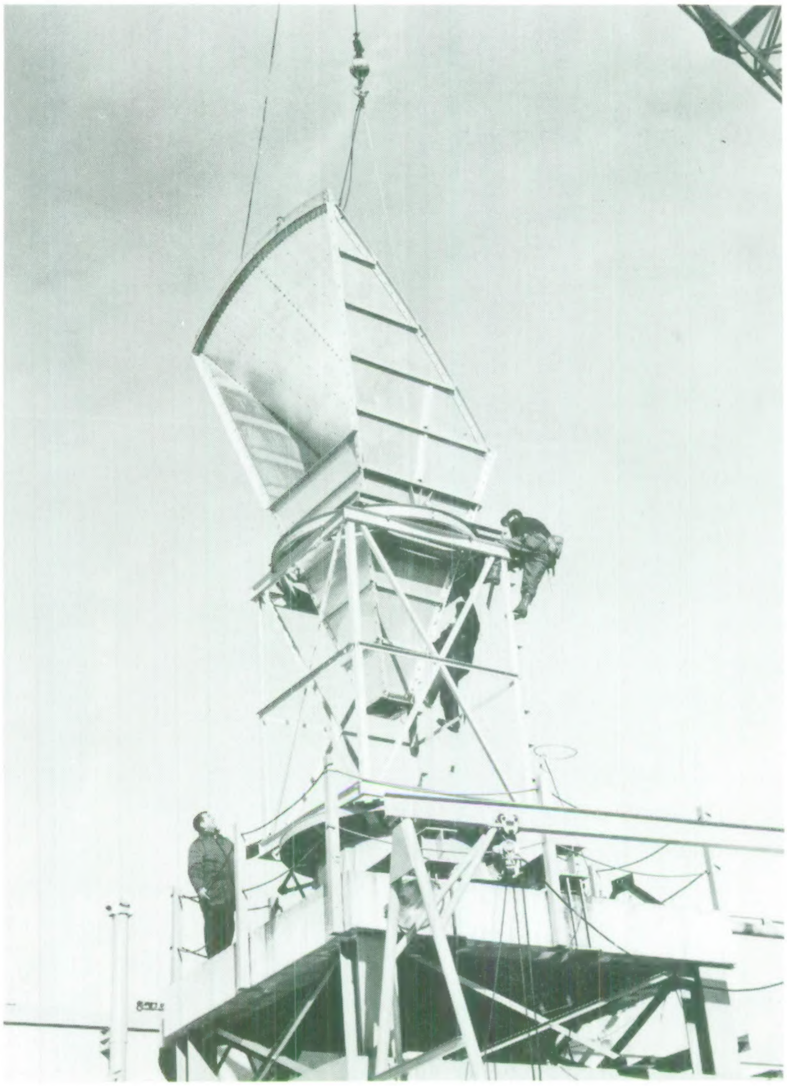

Fig. 2. Horn-reflector antenna being lowered into position on rooftop pedestal.

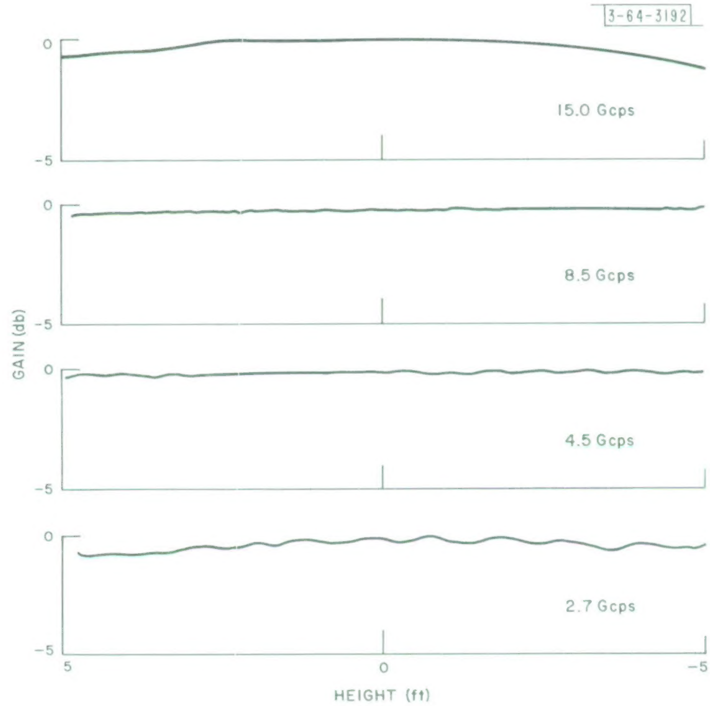

Fig. 3. Amplitude distribution in the aperture plane of horn-reflector antenna.

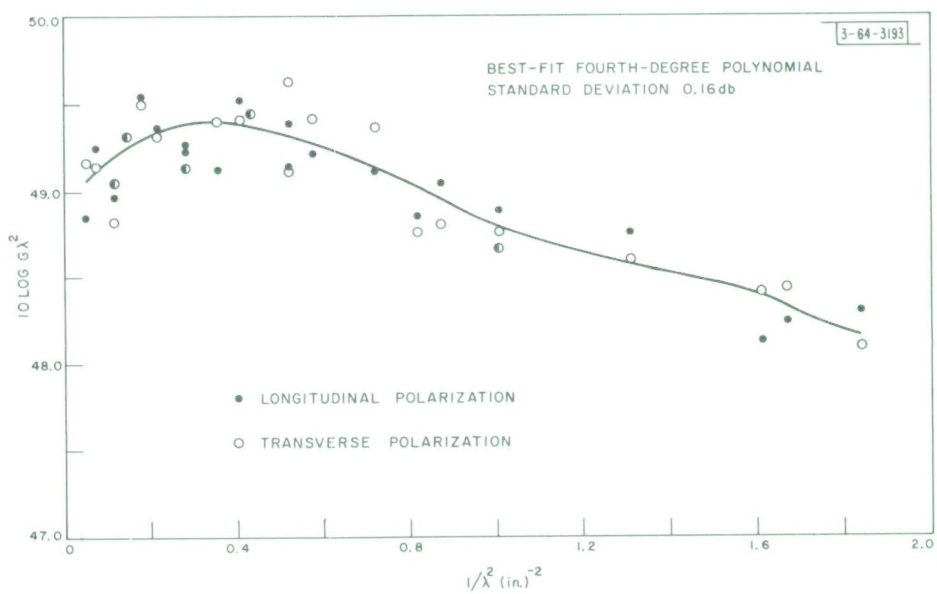

Fig. 4. Gain plot with best-fit polynomial curve.

attenuators were measured with a Weinschel CF-1 audio frequency precision step attenuator as a reference. The CF-1 was first compared with a set of precision coaxial RF attenuators.* These attenuators were measured at their rated frequency of 1.0 Gcps modulated with a 1-kcps square wave and with a bolometer for a detector. The measurements were within the combined tolerances (typical 0.06 db) of the attenuator and the CF-1. With confidence in the technique obtained by the above measurement, the waveguide attenuators to be used in the gain measurement were then calibrated. The fixed waveguide attenuator values were obtained by measurement with the CF-1. Similarly, the deviations between the variable waveguide attenuators and the CF-1 were used to correct the results.

Since far field conditions are more nearly approached at the lower wavelengths, no near field correction was made. On the assumption that the trapezoidally shaped aperture of the horn-reflector antenna is approximately equivalent to an 8-foot-diameter paraboloid, the gains at the shortest wavelengths were increased 0.06 db at 16.0 Gcps through 0.01 db at 7750 Mcps.

The mean deviation of the measurements was estimated to be 0.2 db.

	Peak Errors (db)
Precision attenuators	0.06
Gain standard	0.20
Measurement error	0.30
Range-illumination error	0.15
Average root-mean-square error	0.2

The plotted curve seems to introduce an inaccuracy as large as 0.35 db; however, the manner in which these numbers have been determined must be considered. Specifically, it is more probable that the 0.2-db deviation should have been either added or subtracted to result in the minimum rather than the maximum difference between the plotted point and the curve.

V. ANALYSIS OF MEASURED DATA

The measured data, when plotted as some function of wavelength, will in general show a spread or variability from some smooth curve. To analyze the data we can make one of two assumptions:

(a) A polynomial least-square-fit curve will yield the best estimate of the gain, and the shape of this curve or its deviation from some expected behavior is due to the actual performance of the test antenna.

(b) The measured data will follow a definite predetermined law and any deviations are due entirely to errors in the measurements.

The first method is justifiable because minor oscillations in gain may be due to inherent secondary effects. Such variations have been observed in horn gain standards.[6] The second method is based on the assumption that large-aperture antennas follow theoretical behavior Since it was not possible to completely justify either approach, the data were analyzed by both methods.

In either case, it is desirable to choose the coordinates so that the gross behavior approximates a straight line. The theoretical law was chosen to be

*The manufacturer, Weinschel, states that these figures agree with National Bureau of Standards values.

$$G = \eta \left(\frac{4\pi A}{\lambda^2}\right) \exp[-C(\frac{4\pi\epsilon}{\lambda})^2]$$

where

η = the aperture area efficiency

A = the aperture area

ϵ = the reflector tolerance as measured normal to the surface

C = a correction factor due to the reflector curvature and depends on the f/D ratio or the portion of the surface used.

The above equation may be written in the form:

$$10 \log G\lambda^2 = 10 \log \eta (4\pi A) - C(\frac{4\pi\epsilon}{\lambda})^2 \; 10 \log e \tag{2}$$

which is the straight line.

$$y = a - bx \tag{3}$$

when $10 \log G\lambda^2$ is plotted against reciprocal wavelength squared, and the aperture efficiency is assumed constant. The vertical intercept is a measure of the aperture efficiency, and the reflector tolerance can be obtained from the slope.

Initial data analysis was treated by the polynomial best-fit method. This analysis indicated that there was no significant difference between longitudinal and transverse polarizations, since the mean of the gain difference was only 0.01 db. All the data were therefore combined and a fourth-order polynomial of least-square best-fit was obtained. The result is shown in Fig. 4. The characteristics of this estimate are that:

(a) The mean deviation of all measured points is 0.16 db.

(b) The maximum deviation is 0.35 db.

The data were next analyzed on the assumption that the test-antenna gain followed the straight-line prediction [Eq. (2)] and that any deviations were entirely due to measurement error. An exception was made in the case of data below 4.0 Gcps. Here, the experimental data indicated a definite drop. This phenomenon could, in part, be accounted for by edge diffraction effects and by the fact that at the longer wavelengths, the phase center of the input waveguide moves forward of the focal point. Because some theoretical justification existed for excluding these data from the straight-line assumption, the least-square line was determined only from data above 4.0 Gcps (40 measured points). The low frequency drop was sketched in by hand (see Fig. 5).

The characteristics of this gain estimate are that:

(a) The mean deviation of all data above 4.0 Gcps is 0.166 db, not significantly different from the fourth-order polynomial fit.

(b) The maximum deviation is 0.42 db.

(c) The indicated efficiency is 77.21 percent, whereas the theoretically calculated efficiency is 78.34 percent for longitudinal polarization and 76.13 percent for transverse polarization.

(d) Sixty-five percent of the measured data is within one standard deviation and 97.5 percent is within two. Therefore, the measured data distribution is very closely Gaussian about the straight line.

(e) The reflector tolerance measured normal to the surface is 0.048 inch. This figure is close to the manufacturer's specification of $\pm\frac{1}{16}$ inch.

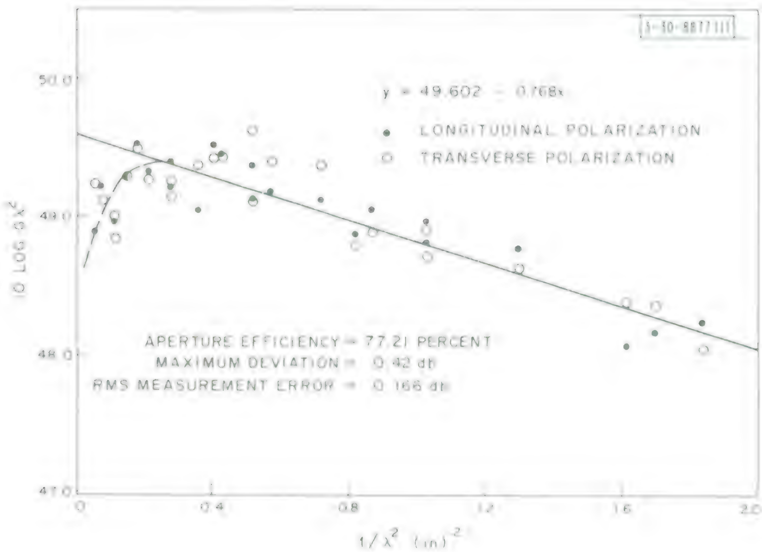

Fig. 5. Gain plot with best-fit straight line.

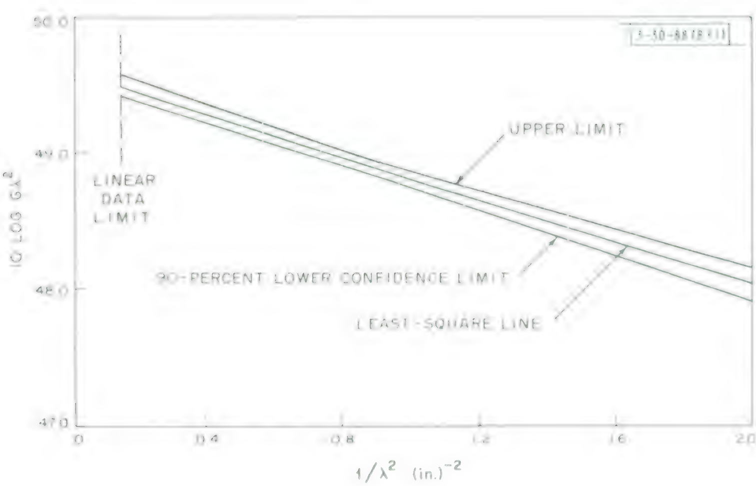

Fig. 6. Confidence limits of gain.

If the linear gain relation is accepted, the methods of linear regression analysis can be applied. These methods permit us to set confidence limits on our gain estimate. This has been done in Fig. 6 where the 90-percent limits are shown. These limits mean that, if the entire experiment were repeated many times with other equipment (attenuators, gain standards, pattern ranges, etc.), physically identical and from the same statistical population, 90 percent of the least-square-fit lines would fall between the confidence limits. Since these limits are about 0.1 db, our estimated gain has this tolerance. The gain above 4.0 Gcps can then be written:

$$10 \log G = 49.60 - \frac{0.77}{\lambda^2} - 10 \log \lambda^2$$

where λ is in inches.

In comparing the two methods, we find that:

(a) The linear analysis permits us to set 90-percent confidence limits (0.1 db), smaller than the mean deviation (0.16 db) for 68 percent of the data of the polynomial method.

(b) The linear analysis ignores any inherent gain deviation from the linear relationship and therefore does not show any possible gain oscillations about the computed gain.

If agreement could be obtained on the net measurement error, choice of method could be decided by certain statistical significance tests. Because the measurement accuracy is difficult to estimate, this cannot be done and both estimates are presented for the user.

In using the estimates, the following points should be noted:

(a) A portion of the polynomial fitted curve is above the straight-line estimate. This indicates that the polynomial estimate gives a higher gain (maximum 0.15 db) than that calculated from the efficiency and reflector tolerance as determined from the straight-line fit.

(b) Although the mean difference in gain for longitudinal and transverse polarization is extremely small (0.01 db), the mean deviation is 0.18 db. Since each polarization difference is calculated at the same frequency from data using the same equipment, this mean deviation is probably caused by changes either in the pattern range characteristics or in the inherent behavior of the horn-reflector antenna for the two polarizations.

(c) The gain estimated by either method is subject to a fixed bias which no analysis can eliminate. A bias could arise if a major portion of the test equipment used were calibrated by the same master standard or it could be a result of the experimental method or procedure of measurement. It is believed, however, that any bias would be extremely small.

APPENDIX

ERROR IN GAIN MEASUREMENT DUE TO GROUND WAVE

Consider a vertical field distribution due to the sum of

(1) A plane wave normal to the test antenna.

(2) A ground-reflected or interfering wave of amplitude a and relative phase φ arriving at any angle α normal to the test antenna.

The aperture field is

$$e(y) = 1 + a \exp[j(\frac{2\pi}{\lambda} y \sin\alpha + \varphi)] \qquad (A-1)$$

In a ground-reflection test range, the geometry is adjusted so that a field maximum exists at the test-antenna center, or $\varphi = 0$.

A gain standard, located at the test-antenna center will receive a power proportional to

$$P_s = G_s(1 + a)^2 \quad . \qquad (A-2)$$

The test antenna integrates the field across its aperture and yields the response:

$$P_T = G_T \left[\frac{\left| \int_{-y_o}^{y_o} \{1 + a \exp[j(\frac{2\pi}{\lambda} y \sin\alpha)]\} f(y)\, dy \right|}{\int_{-y_o}^{y_o} f(y)\, dy} \right]^2 \qquad (A-3)$$

where f(y) is the test-antenna taper.

Equation (A-3) can be integrated with the result that the ratio of test antenna to gain standard powers is:

For uniform illumination, $f(y) = 1$;

$$\frac{P_T}{P_s} = \frac{G_T}{G_s} \frac{\left(1 + a \frac{\sin \chi_o}{\chi_o}\right)^2}{(1 + a)^2} \quad . \qquad (A-4a)$$

For cosine illumination, $-f(y) = \cos \frac{\pi}{2} \frac{y}{y_o}$;

$$\frac{P_T}{P_s} = \frac{G_T}{G_s} \frac{\left[1 + a(\frac{\pi}{a})^2 \frac{\cos \chi_o}{(\pi/2)^2 - \chi_o^2}\right]^2}{(1 + a)^2} \qquad (A-4b)$$

where $\chi_o = (2\pi/\lambda)\, y_o \sin\alpha$, and the aperture extends from y_o to $-y_o$.

Equations (A-4a) and (A-4b) then represent the error made with the test antenna directed at the source. The measured gain is lower than the true gain. The positive corrections are plotted in Figs. A-1 and A-2 against the parameter r which is the amount of the aperture field at the aperture edge.

$$r = \frac{1 + a^2 + 2a \cos \chi_o}{(1 + a)^2} \quad . \qquad (A-5)$$

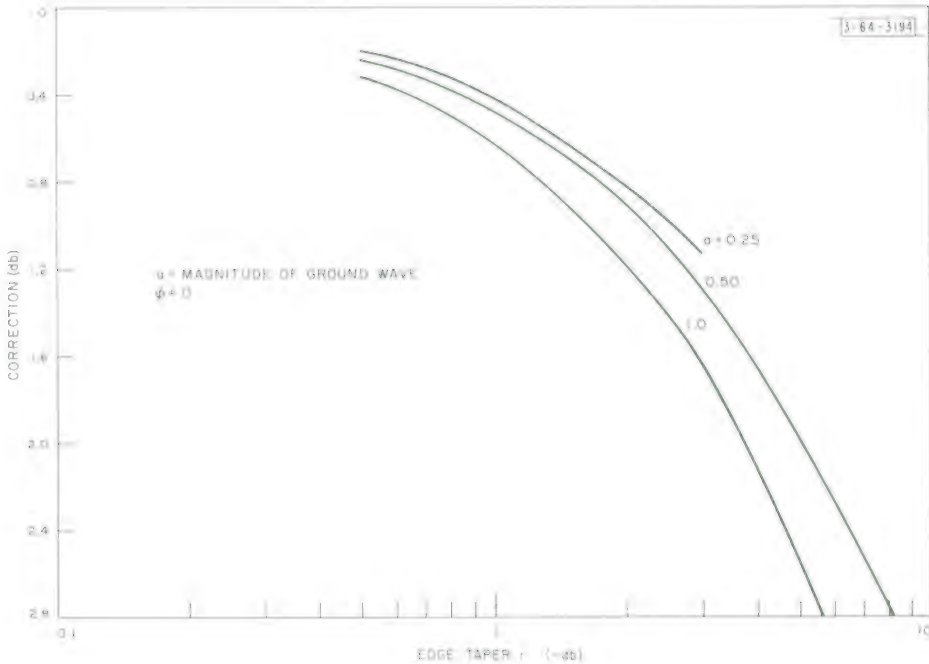

Fig. A-1. Correction for uniform illumination.

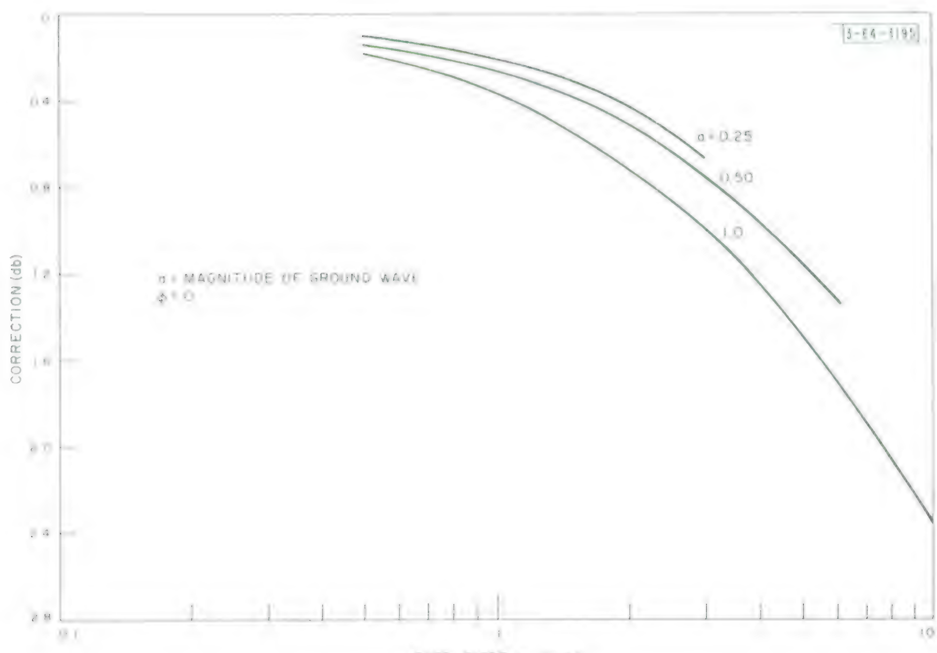

Fig. A-2. Correction for cosine illumination.

The largest variation of the aperture probed field was found to be 0.62 db at 15.0 Gcps. Here, the transmitting antenna was a two-foot dish located two feet above the ground plane. The antenna separation was 2030 feet. The angle α calculates to

$$\alpha = \frac{4}{2030} = 0.00197 \; (0.113°) \quad .$$

Since the source antenna HPBW is about 2.3°, we suspect that our constant a is close to unity.

Figures A-1 and A-2 indicate that this pattern range error is 0.20 db and 0.35 db for cosineal and uniform illumination, respectively.

Actually, in performing the gain measurements, the test antenna is tilted for maximum response and thereby recovers some of this loss.

Tilting the antenna by an angle δ results in an output (uniform illumination) of

$$P_T = G_T \left[\left| \int_{-y_o}^{y_o} \{1 + a \exp[j(\frac{2\pi}{\lambda} \; y \sin\alpha)]\} \exp[j \frac{2\pi}{\lambda} \; y \sin\delta] \, dy \right| \right]^2 \tag{A-6}$$

which is

$$G_T \left[\frac{\sin c\delta}{c\delta} + \frac{a \sin c(\delta + \alpha)}{c(\delta + \alpha)} \right]^2 \quad .$$

This can be differentiated to find the tilt for maximum output. To a first approximation,

$$\delta = \frac{-a\alpha}{1 + a} \quad . \tag{A-7}$$

For a = 1, maximum output is obtained midway between the direct and reflected wave.

For our case, the amount recovered by tilting for maximum output is

$$\frac{\left(\dfrac{\sin \chi_o/2}{\chi_o/2} + \dfrac{\sin \chi_o/2}{\chi_o/2} \right)^2}{\left(1 + \dfrac{\sin \chi_o}{\chi_o} \right)^2} = 1.047 \quad \text{(or 0.20 db)} \quad .$$

Therefore, the error is 0.35 to 0.20 or 0.15 db. For other frequencies, and for horizontal polarization, the error is smaller.

ACKNOWLEDGMENT

The authors wish to express their appreciation to L. J. Ricardi for his helpful criticisms and suggestions.

REFERENCES

1. R. W. Friis and A. S. May, "A New Broadband Microwave Antenna System," Trans. AIEE 77 (Communications and Electronics, No. 35), 97 (March 1958).
2. A. B. Crawford, D. C. Hogg and L. E. Hunt, "A Horn-Reflector Antenna for Space Communication," Bell System Tech. J. 40, 1095 (July 1961).
3. H. G. Weiss, "The Haystack Experimental Facility," Technical Report 365, Lincoln Laboratory, M. I. T. (15 September 1964), DDC 608272.
4. A. Cohen and A. W. Maltese, "The Lincoln Laboratory Antenna Test Range," Microwave J. 4, No. 4, 57 (April 1961).
5. E. V. Jull and E. P. Deloli, "An Accurate Absolute Gain Calibration of an Antenna for Radio Astronomy," IRE, PTGAP, AP-12, No. 4, 439 (July 1964).
6. W. T. Slayton, "Design and Calibration of Microwave Antenna Gain Standards," NRL Report No. 4433 (November 1954).
7. S. Silver, ed., Microwave Antenna Theory and Design, Radiation Laboratory Series, M. I. T. (McGraw-Hill, New York, 1949), Vol. 12, pp. 196-199.

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